Title: The functional anatomy and connectivity of thought insertion and alien control of movement

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The functional anatomy and connectivity of thought insertion and alien control of movement

Abstract

Alien control phenomena are symptoms reported by patients with schizophrenia whereby feelings of control and ownership of thoughts and movements are lost. Comparable alien control experiences occur in culturally influenced dissociative states. We used fMRI and suggestions for automatic writing in highly hypnotically suggestible individuals to investigate the neural underpinnings of alien control. Targeted suggestions selectively reduced subjective ratings of control and ownership for both thought and movement. Thought insertion was associated with reduced activation of networks supporting language, movement, and self-related processing. In contrast, alien control of writing movement was associated with increased activity of a left-lateralised cerebellar-parietal network and decreased activity in brain regions involved in voluntary movement, including sensory-motor hand areas and the thalamus. Both experiences involved a reduction in activity of left supplementary motor area (SMA) and were associated with altered functional connectivity between SMA and brain regions involved in language processing and movement implementation. Collectively these results indicate the SMA plays a central role in alien control phenomena as a high level executive system involved in the sense that we control and own our thoughts and movements.

1. Introduction

As humans we can readily detect whether our bodily movements are self-generated or externally caused, and typically experience a sense of control and ownership of our thoughts. These fundamental features of experience are disrupted in psychiatric symptoms of alien control, where patients describe their thoughts and/or their movements as under the control of an external agent (Frith, 2005). For example, during the experience of thought insertion (TI), the patient "believes that thoughts that are not his own have been inserted into his mind" (Mullins & Spence, 2003). Mellor's classic example (Mellor, 1970) cites a patient's experience: 'I look out of the window and I think the garden looks nice and the grass looks cool, but the thoughts of Eamonn Andrews [TV presenter] come into my mind. There are no other thoughts there, only his. . . He treats my mind like a screen and flashes his thoughts onto it like you flash a picture.' Similarly, experiences of alien control of movement (ACM) involve the experience that movement is under the control of some force or entity outside the self, as in patient reports, such as, 'they inserted a computer in my brain. It makes me turn to the left or right'; or "my fingers pick up the pen but I don't control them" (Mellor, 1970).

Previous studies of the cognitive and neural bases of alien control phenomena have tended to focus on mechanisms underlying alien control of movement (Frith, 2005). We know of no published studies using functional imaging to investigate brain activity during thought insertion. Nevertheless,

neurocognitive models of both thought insertion and alien control of movement have been proposed in which both phenomena are the result of aberrant self-monitoring (Haggard, Cartledge, Dafydd, & Oakley, 2004; Szechtman, Woody, Bowers, & Nahmias, 1998). At a neural level, problems with self-monitoring have been linked to a 'forward model' where processing of movement-related sensory feedback involving a parietal-cerebellar network is subject to feed-forward inhibition during voluntary movements (Synofzik, Vosgerau, & Newen, 2008). In this model, alien control of movement results from failure of feed-forward inhibition, so that self-generated movements are experienced as though they are externally caused (Frith, 2005). A previous study investigated the neural correlates of alien control of movement by employing hypnotic suggestion and Positron Emission Tomography (PET) in healthy participants (S. J. Blakemore, Oakley, & Frith, 2003). Experimental conditions included misattributions of self-generated movement while participants produced repetitive vertical movements with their left arm. These 'deluded passive movements' were associated with significantly greater activations in bilateral cerebellum and parietal cortex relative to normal self-generated voluntary movements. Failure to attenuate sensory processing for what in reality were self-generated movements was proposed to underlie the observed increases in cerebellar-parietal activity during deluded passive movements (S. J. Blakemore et al., 2003).

Deeley et al., (2013b) offered an alternative account of the experience of alien control of movement. This 'executive control' model proposes that alien control phenomena may be mediated by altered activity in motor planning regions, in particular the supplementary motor area (SMA) (Deeley et al., 2013b). Reduced connectivity between SMA and motor implementation regions, including M1, during suggested involuntary compared to voluntary joystick movements was observed in our prior study. This finding is consistent with the proposed role of the SMA in the control and ownership of movements (Fried, Mukamel, & Kreiman, 2011; Grafton, Mazziotta, Woods, & Phelps, 1992; Haggard, 2008; Haggard & Magno, 1999; Nachev, Kennard, & Husain, 2008; Penfield & Welch, 1951). While cognitive neuroscience research to date has focused on alien control of movement, thought insertion symptoms remain twice as prevalent in patients with schizophrenia (Grafton, Mazziotta, Presty, et al., 1992; Mellor, 1970). Both thought insertion and alien control of movement also occur in other psychiatric disorders (Mullins & Spence, 2003) and have been observed in the general population (Wiles et al., 2006). Non-pathological instances of thought insertion and alien control of movement include culturally influenced dissociative phenomena linked to practices such as mediumship and automatic writing, which have been widely reported across different cultures and periods of history (Crapanzano & Garrison, 1977; Deeley, 2013; Ellenberger, 1970; Vitebsky, 2001).

By analogy with the forward model account of alien control of movement, it has been suggested that the experience of thought insertion may result from impaired monitoring of self-generated thought (Feinberg, 1978; Frith, 2005). This proposal has been criticised on the grounds that thoughts, unlike movements, do not have well defined sensorimotor characteristics that could inform feed-forward inhibition of self-monitoring systems (Synofzik et al., 2008). The alternative 'executive control' model - assuming an analogy with the proposed role of the SMA in alien control of movement - would argue that a disruption of SMA function during generation of thoughts produces a loss of perceived control and ownership. However, a method for the experimental study of the neural basis of thought insertion does not exist. Experimental investigation of these unresolved questions about thought insertion, and its relation to alien control of movement, is especially challenging as thought is a covert process

(Mullins & Spence, 2003). Also, the effects observed in our prior study involving simple joystick movements may not generalise to complex movements such as handwriting.

To investigate the neural bases of thought insertion and alien control of complex movements we extended the approach described in previous studies (Quinton Deeley et al., 2013; Walsh et al., 2014) by combining fMRI and suggestions for automatic writing in highly hypnotically suggestible individuals, employing a sentence completion task where thought and movement occur sequentially and discretely (see Figure 1a). Writing involves expressing thoughts in words and then using hand movements to write the words down (Beeson, 2004). Cognitive and clinical models suggest that both thought and movement components of writing, though clearly linked, are nevertheless separable (Magrassi, Bongetta, Bianchini, Berardesca, & Arienta, 2010; Scarone et al., 2009). Furthermore, subjective reports of automatic writing suggest that the thought content and motor act of writing can be independently experienced as externally caused (Britton, 1997). Thus, a handwriting task provides a model system to investigate both types of alien control where targeted suggestions can be employed to generate separate experiences of thought insertion and alien control of movement.

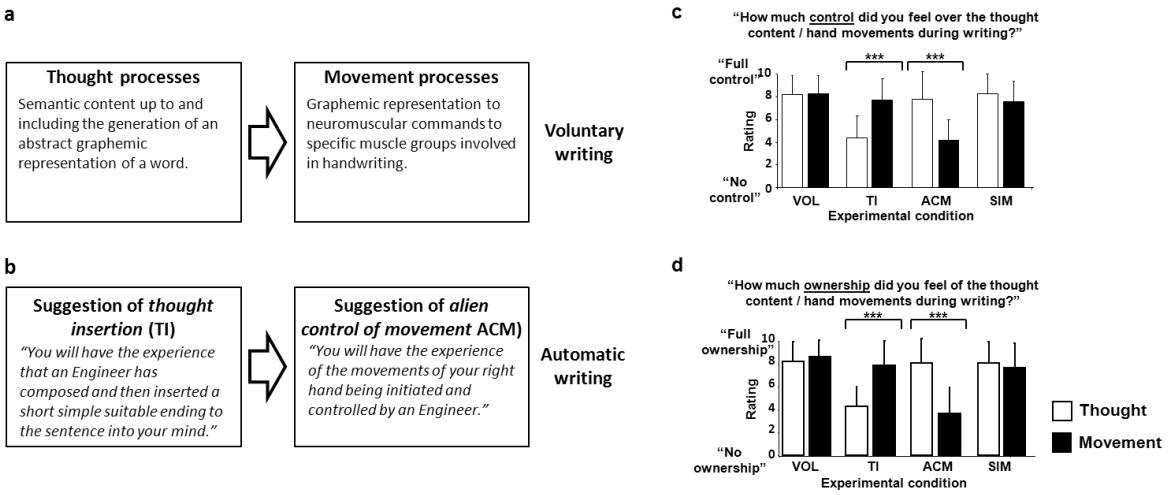

Figure 1. Schematic of experimental rationale. **a)** According to models of writing (Sage & Ellis, 2004), production of a written word involves serial thought and movement processes. **b)** This linear order allows the thought and movement components of writing to be targeted independently via suggestion to produce automatic writing (See also Table 4). Mean control **c)** and ownership **d)** ratings for voluntary writing (VOL), during suggestions of thought insertion (TI) and alien control of movement (ACM) experiences, and instructions for simulation of alien control of movement (SIM). Standard deviations are shown as error bars. Note the double dissociation for the thought and movement components of writing for control and ownership ratings, in both the thought insertion (TI) and alien control of movement (ACM) conditions ($p < 0.001$; 4 middle bars, graphs a and b).

At a phenomenological level, we hypothesised that targeted suggestions would be associated with reductions in control and ownership of the thought and motor components of writing respectively, in line with previous findings (Walsh et al., 2014). At a neural level, we made predictions based on the forward and executive control models informed by previous studies (S. J. Blakemore et al., 2003; Q. Deeley et al., 2013; Synofzik et al., 2008). Specifically, in keeping with the forward model of motor control, we predicted that suggested alien control of complex movement would be associated with increased activity of a bilateral cerebellar-parietal network, as previously described for alien control

of simple repetitive movement (S. J. Blakemore et al., 2003). However, following criticisms of the application of comparator or forward models to thought insertion (Synofzik et al., 2008), we did not predict increases in activity in brain regions involved in self-monitoring during thought insertion. Since thought is closely linked to language production (Dennett, 2008; Pinker, 1994), we postulated that the experience of thought insertion would involve altered activity in temporal and frontal cortical language generation areas (Kim, Relkin, Lee, & Hirsch, 1997; Price, 2000), rather than changes in cerebellar–parietal activation. Also, in keeping with the executive control model, we predicted that both alien control of movement and thought would be associated with altered connectivity between supplementary motor area (SMA) and modality specific regions. We also explored changes in connectivity with sensorimotor cortex. In the case of SMA, we predicted that alien control of movement would be associated with reduced connectivity with motor implementation regions (Quinton Deeley et al., 2013), while alien control of thought would be associated with reduced connectivity with temporal-frontal regions involved in language generation.

2. METHOD

2.1 Participants

Eighteen right-handed [Edinburgh Handedness Inventory (Oldfield, 1971) mean scores: right hand: 18 (SD=1); left hand: 1 (SD=2)], highly hypnotically suggestible [Harvard Group Scale of Hypnotic Susceptibility: Form A (Shor and Orne, 1963); Scale range 0-12; High > 8 mean score = 9.7; SD=1.4] native English-speaking participants (13 female), mean age 26.2 (SD=8.3) years were recruited with informed consent from a pool of approximately 350 volunteers who had been screened for suggestibility. All participants were tested behaviourally in a mock training scanner to ensure compatibility prior to participating in the fMRI study (Walsh et al., 2014). This research was conducted in accordance with Research Ethics Committee approval at King's College London.

2.2 Procedure

The procedures were largely based on a preliminary behavioural study (Walsh et al., 2014). Briefly, after a hypnotic induction procedure, consisting of visual fixation combined with instructions and suggestions for focused attention and progressive relaxation (Deeley et al., 2012; D. A. Oakley, Deeley, & Halligan, 2007), targeted hypnotic suggestion was used to produce automatic writing in healthy participants in order to create separate experiences of alien control for thought and movement during a sentence completion task (Figure 1 and Table 4) [For background information on hypnotic techniques and the use of hypnotic suggestion as a research tool in cognitive neuroscience see Oakley & Halligan (2009, 2013) and Halligan & Oakley (2013)]. During the suggestions, an 'engineer' was nominated as the agent of alien control. Participants were presented with 10 sentence stems, i.e. 10 trials, in each experimental block. Each trial had an interval for generation of a sentence ending ('preparation interval') and an interval for writing it down ('movement interval'). Stimulus words used for the sentence stems were based on common nouns found in the British National Corpus and were matched across conditions for frequency in written and spoken English. At the end of each block, participants verbally rated ('0' – '10') their subjective experience for each suggested (TI and ACM)

condition immediately following each scanning block with respect to: (i) control ('0' = 'no control', and '10' = 'full control'); (ii) ownership ('0' = 'no ownership', and '10' = 'full ownership') and (iii) awareness ('0' = 'no awareness', and '10' = 'full awareness'). Additionally ratings were taken for subjective 'depth of hypnosis,' also rated from '0' ('not at all hypnotized') – '10' ('as hypnotized as I've ever been'). The four randomized experimental writing conditions differed only in terms of whether thought or movement was attributed to 'self' or to 'alien' control (Table 4). Participants were hypnotized and kept their eyes closed throughout.

Each trial consisted of a thought and movement interval. At the start of the preparation interval, participants were presented with a sentence stem e.g. 'The dog…', which was repeated once. Participants were instructed to think of an ending (voluntary thought) or, in the thought insertion condition, it was suggested that 'an engineer is inserting a sentence ending into your mind'. A tone marked the start of the movement interval. Upon presentation of the tone, participants were instructed to write down the sentence ending from the preparation interval (voluntary movement). Alternatively, during the alien control of movement condition it was suggested to participants that 'an engineer is controlling your hand movements as you write'. A second tone marked the end of the trial. Each trial was succeeded by an 8 second rest interval. Trial interval durations were jittered by up to 500ms from trial to trial. Video recordings were made throughout the task to confirm adherence to the instructions and record movement initiation times.

Table 4. The four experimental conditions.

Condition	Suggestion / Instruction	Focus of control	
		Thought component	*Movement Component*
1. Voluntary (VOL)	'When you hear the sentence stem, *your job is to quickly think of a short simple suitable ending* and then hold it in your mind and wait for the 1st tone. When you hear this tone, write down the *short simple ending to the sentence* that you held in your mind. Once you hear the 2nd tone – stop writing immediately.'	Self	Self
2. *Thought insertion* (TI)	'When you hear the sentence stem, you will have the experience that an Engineer has composed and then inserted *a short simple suitable ending to the sentence* into your mind. This happens immediately after the sentence stem, and before the 1st tone is heard - When you hear the 1st tone, recall the Engineer's *short simple ending* to the sentence and write it down in your normal handwriting - However, the Engineer has no control over your movements.'	Alien	Self
3. *Alien control of movement* (ACM)	'When you hear the sentence stem, then *think of a short simple suitable ending to the sentence,* hold it in your mind, and wait for the 1st tone. When you hear this tone, you will have the experience of the *movements* of your right hand being initiated and controlled by an Engineer; these movements cause the marker to write down the sentence ending which you kept in mind, each time. Just hold the marker, the rest will happen by itself - However, the Engineer cannot control your thoughts, only your hand movements when writing. You and you alone, think of *the endings to each sentence and only you hold these in your mind.'*	Self	Alien
4. Simulation (SIM)	'As you write, maintain your normal handwriting, but this time and this time only, *just pretend* that the movements of your right hand are being initiated and controlled by an Engineer. You and you alone, cause the marker to move, no one else.'	Self	Self

2.3 Image Acquisition Parameters

Functional MRI was carried out at the Centre for Neuroimaging Sciences, King's College London, UK. A GE Signa HDx 3.0T scanner was used with an 8-channel head coil to acquire T2* gradient echo, echoplanar imaging (GE-EPI) data (TR = 2000msec, TE = 30msec, Flip angle = 80°) in the near-axial orientation, parallel to the anterior-posterior commissure (AC-PC) line. Whole-brain volumes (150 per participant, per experimental condition), consisting of 38 slices (3.3mm thick, 0.3mm slice gap), were imaged using a top down sequential acquisition (matrix size = 64 x 64, FoV = 230mm^2). Structural high-resolution EPI (HR-EPI) scans were also acquired for each participant with the following parameters: TR=3000ms, TE=30msec, Flip angle = 90, 43 slices (3.3m, 0.3mm slice gap), matrix size = 128 x 128, FoV = 240mm^2.

2.4 Neuroimaging data analysis

Functional images were processed and analysed in SPM8 (http://www.fil.ion.ucl.ac.uk/spm). All images were initially realigned to first image and then their mean image. The mean image was spatially normalized to the SPM8 EPI template and spatially smoothed (8 mm FWHM Gaussian kernel), and high-pass filtered (128 s). For the single subject first level analysis, the preparation onsets and durations, movement onsets and durations and head motion parameters were entered as regressors. The group ANOVA second level analysis included all experimental conditions for all participants. All images were corrected for multiple comparisons at the cluster level ($p<0.05$) with voxel threshold $p<0.001$.

2.5 PPI Procedure

We conducted a psycho-physiological Interaction (PPI) analysis to assess the influence of suggestions for TI and ACM on changes in functional connectivity associated with response preparation (preparation interval) and execution (writing interval) during the sentence completion task. Two seed regions were chosen based on the group-analysis peak voxel results of the General Linear Model (GLM) for writing in the normal alert state,: (1) the left supplementary motor area (SMA; MNI coordinates = [-8, 4, 60]) for its key role in movement preparation (Nachev et al., 2008), and its association with control and ownership of movement (Deeley et al. 2013) and (2) the left primary motor-sensory region, encompassing M1 because of its dual (language and movement) role in writing. For simplicity we refer to this seed as 'M1' (MNI coordinates = [-28, -32, 52]). The seed for the PPI analysis for each participant was defined as the eigenvalue for a 6mm radius sphere around the peak activation nearest the seed coordinates. In order to ensure the data were from the same functional locale across all individuals, we excluded participants for whom the Euclidian distance between the peak activation voxel per condition closest to the seed coordinates exceeded 6 mm. Therefore, the PPI analysis of the SMA seed for the preparation and movement intervals included 18 and 15 participants respectively while for the M1 seed preparation and movement intervals included 10 and 15 participants respectively. We used a voxel-wise threshold of $p<0.01$, with statistical inference based on a cluster statistics threshold of $P<0.05$ corrected for multiple comparisons. For the PPI analyses the single-subject models included regressors for the seed region, the task design (from the preparation and movement intervals), their interaction (Friston et al., 1997), and the six movement parameters. The PPI contrast image was entered into a flexible factorial ANOVA model including 7 experimental conditions. For each seed region, these individual PPI contrast images were then entered into a two-sample t-test at the second (group) level to test between condition differences.

3. RESULTS

3.1 Self-ratings and writing behaviour

To determine if the focused attentional state which we term 'hypnosis' was established and maintained across the experimental conditions, an ANOVA was performed with the factor of experimental condition, with self-ratings (depth of hypnosis) as the dependent variable. Subjective self-ratings for depth of hypnosis (mean rating = 7.8) did not differ across conditions ($F<1.5$). In order to determine if the various suggestions were successful in altering subjective experience, a repeated

measures ANOVA was performed with the factors of cognitive and motor components of writing (thought vs. movement) and experimental condition (4 conditions), with self-ratings (awareness, control, ownership) as dependent variables. Critically, we found that subjective feelings for control and ownership of thought and movement components of writing could be independently manipulated (Figure 1c,d; Interaction: $F(1, 17)=36.98$; $p<0.0001$).

During suggestions of thought insertion, participants' ratings of control and ownership of thought but not the movement component of writing were reduced relative to the voluntary control condition. During suggestions of alien control of movement, the reverse was true i.e. there were reduced ratings for control and ownership of movement but not for the thought component of writing. To control for the possibility that participants were simulating the suggested effects, we also included a simulation condition (SIM) where participants were instructed to "just pretend" that an engineer was controlling their hand movements as they wrote. There was an interaction between ratings for simulation, and both thought insertion and alien control of movement conditions (all $F>27.2$), indicating that subjective experience was rated differently between the simulation (SIM) and suggestion (TI, ACM) conditions. There were no interactions between ratings for voluntary writing and simulation. ($F<3.8$; see Figure 1). Collectively these results provide behavioural evidence that participants were not simulating during the suggestion (TI, ACM) conditions.

While the conditions reported here did not employ targeted suggestions to reduce awareness during automatic writing, ratings for awareness nevertheless followed a similar pattern as for control and ownership. Relative to voluntary control, awareness of movement, but not thought, was reduced during suggestions for ACM. Relative to voluntary control, awareness of thought, but not movement, was reduced during suggestions for TI. However, estimates of effect size were lower for awareness ratings (partial Eta squared = 0.347) than control (0.634) and ownership (0.684) ratings for the 2 (condition: TI vs. ACM) x 2 (components of writing: thought vs. movement) interactions. Overall, suggestions for thought insertion and alien control of movement produced a greater effect on respective self-ratings of control and ownership than on awareness. A subsequent regression analysis of the behavioural awareness ratings with brain activity did not show any significant or trend relationships, including in areas of altered activity with suggested loss of control (all $p > 0.41$ for the TI contrast, and all $p > 0.15$ for the ACM contrast; see below). In summary, the suggestions produced the intended effects and these were not paralleled in the simulation condition.

Writing behaviour as measured by quantity of writing produced, onset latency, duration of writing and semantic content of words (Davis, 2005) did not differ across conditions. Also, the number of words (mean=2.7; SD=0.8) and characters (mean=11.2; SD=3.7) written per sentence-ending did not differ across experimental condition ($Fs<1.5$). Similarly, onset latency (mean=1613; SD=537 msec) and duration of writing (mean=6155; SD=1514 msec) as measured using video analysis did not differ ($Fs<2.9$). There were no differences in *written word frequency* or *imageability* ($Fs<1.6$) (Walsh et al., 2014). In summary, the written form and semantic content of the writing were consistent across conditions.

3.2 Imaging results

Activations produced by writing in the normal alert state (i.e. before the hypnotic induction procedure) showed that (i) in the preparation interval, left SMA, left inferior frontal operculum (Broca's area) and right cerebellum were significantly activated relative to rest, and (ii) in the movement interval left primary and somatosensory cortices, as well as right cerebellum, were

activated. Importantly, the contrast of suggested ACM (ACM condition) and simulated ACM (SIM condition) showed significant differences (Table 2), indicating that participants were not engaging in simulation strategies.

3.3 Thought insertion contrast (TI vs. VOL)

To identify brain regions involved in the experience of thought insertion when it was suggested to participants that ''the engineer is inserting sentence endings into your mind" during the preparation interval, activity in the voluntary and thought insertion experimental conditions were compared. During the preparation interval, the thought insertion relative to the voluntary condition was associated with a relative decrease in activity in left SMA, basal ganglia and striatal areas, and bilaterally in the precuneus and in temporal areas. Reduced activation was also observed in right superior occipital cortex and thalamus (Table 1a; Figure 2a). During the movement interval, there was a relative decrease in activity in left mid-temporal, SMA, precentral, inferior frontal and superior temporal and occipital as well as right superior frontal gyri. Bilateral reductions were observed in mid frontal gyri and mid-cingulum (see Table 1a).

Table 1. SPM results for the contrast between a) suggested thought insertion (TI) and voluntary writing (VOL) and b) suggested alien control of movement (ACM) and voluntary writing (VOL) for the preparation and movement intervals of a trial.

Hemisphere	Anatomical Region	MNI coordinates x, y, z	BA	Cluster size	Z value	Cluster-level p corrected
a) THOUGHT INSERTION CONTRAST						
Preparation Interval		**VOL > TI**				
L	SMA	-10, -14, 58	6	5348	5.58	0.000
R	Thalamus	14, -28, 8	-		5.13	
L	Pallidum	-22, 0, 2	-		5.01	
R	Putamen	26, 16, 6	48	925	5.31	0.001
L	Superior Temporal	-42, -42, 12	41	849	4.90	0.001
L	Inferior Temporal	-52, -56, -6	37		4.80	
R	Superior Occipital	24, -70, 34	19	346	4.60	0.045
R	Precuneus	16, -66, 44	7		3.91	
L	Precuneus	-8, -58, 46	-	317	4.38	0.048
R	Superior Temporal	62, -34, 16	42	459	4.35	0.018
R	Mid-Temporal	48, -46, 14	21		3.54	
Movement interval		**VOL > TI**				
L	Mid-Temporal	-46, -42, 10	21	4391	5.14	0.000
L	Precentral	-20, -32, 76	6		4.73	
L	Superior Temporal	-34, -18, 66	48		4.67	
L	Superior Occipital	-14, -74, 42	19	2596	5.04	0.000
R	Mid-Cingulum	10, 4, 44	24		4.72	
L	Mid-Cingulum	-6, -30, 44	23		4.53	
L	Mid-Frontal	-34, 34, 24	46	439	4.27	0.024
L	Inferior Frontal	-38, 30, 18	48		3.91	
R	Mid-Frontal	38, 40, 26	48	562	4.02	0.010
R	Superior Frontal	22, 50, 20	46		3.94	
b) ALIEN CONTROL OF MOVEMENT CONTRAST						
Preparation Interval		**VOL > ACM**				
L	SMA	-8, -14, 58	6	1938	5.25	0.000
L	Postcentral	-20, -32, 76	4		4.68	
L	Precentral	-34, -18, 66	6		4.60	
	ACM > VOL					

L	Cerebellum	-18, -52, -14	37	590	4.27	0.006
L	Lingual	-18, -84, 2	18		3.69	
Movement Interval		**ACM > VOL**				
L	Angular	-40, -68, 38	19	436	4.13	0.025

Notes: BA = Brodmann Area

Table 2. SPM results showing differences in activation for the contrast between suggested alien control of movement (ACM) and instructed simulation of alien control of movement (SIM).

Hemisphere	Anatomical Region	MNI coordinates x, y, z	BA	Cluster size	Z value	Cluster-level p corrected
Preparation Interval		**ACM > SIM**				
L	Cerebellum	-14, -60, -12	18	991	4.85	0.000
Movement interval						
R	Posterior Cingulum	8, -38, 30	23	1541	5.66	0.000
L	Posterior Cingulum	-10, -48, 34	23			
L	Mid-Cingulum	0, -38, 44	-			
L	Angular	-48, -68, 32	39	1095		
L	Inferior Parietal	-48, -56, 42	39			
R	Superior Medial Frontal	12, 50, 30	32	3288		
L	Superior Medial Frontal	-2, 32, 52	8			
L	Superior Frontal	-16, 34, 38	32			

Notes: BA = Brodmann Area

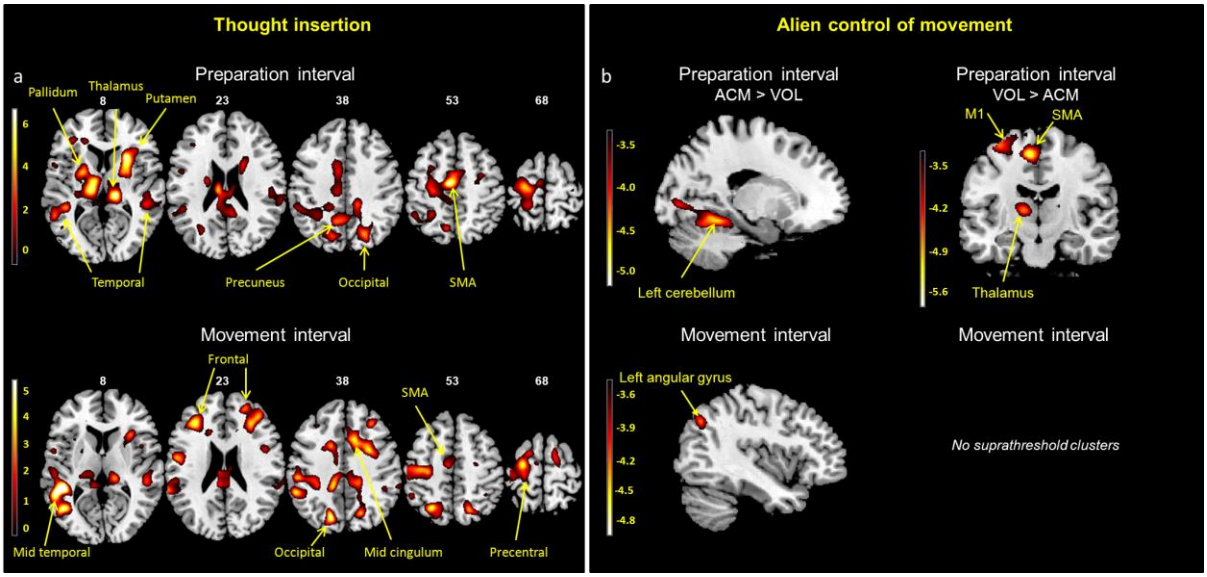

Figure 2. a) Neural correlates of thought insertion (VOL > TI). Reduced brain activity during suggestions for the experience of thought insertion during the preparation (top) and movement (bottom) intervals of a trial. No significant changes in activation were observed for the reverse contrast (TI > VOL). **b)** Neural correlates of the experience of alien control of movement (ACM). Comparison of panels a) and b) above, indicate distinct patterns of brain activity for the different targeted suggestions. No changes in activation were observed for the movement interval in the VOL > ACM contrast.

3.4 Alien control of movement contrast (ACM vs. VOL)

We compared the voluntary (VOL) and alien control of movement (ACM) conditions (Figure 2b). During the preparation interval, relative to voluntary movement, ACM was associated with decreased activity in left hemisphere brain regions that are known to be active during voluntary movement – specifically left SMA extending to sensorimotor areas. Also during the movement interval, reduced activation occurred in left middle temporal gyrus, precentral and superior occipital areas, in right superior frontal gyrus, and bilaterally in mid-cingulate cortex and mid-frontal areas. Writing movements attributed to alien control resulted in significantly increased activation in the cerebellum (preparation interval) and parietal cortex (movement interval), specifically the left angular gyrus (Table 1b; Figure 2b). Cerebellar activity increased during preparation only, while increased parietal activity was confined solely to the movement phase.

3.5 Functional connectivity patterns for the TI and ACM contrasts.

A psychophysiological interaction (PPI) analysis (Friston et al., 1997) was conducted to assess the influence of suggestions for thought insertion and alien control of movement on changes in functional connectivity with SMA associated with response preparation and execution during writing.

3.6 Psychophysiological interaction (PPI): Thought insertion contrast (TI vs. VOL)

During suggestions of thought insertion in the preparation interval functional connectivity (FC) decreased between the SMA seed and left mid-cingulum, left SPL and right mid-frontal gyrus. In the movement interval, FC decreased between the SMA and bilateral precuneus and left calcarine gyrus ($p = 0.055$). In the preparation interval, the M1 seed showed increased FC with left cerebellum and right superior temporal pole. No changes in connectivity were observed during the movement interval for the M1 seed (see Figure 3a and Table 3a).

3.7 Psychophysiological interaction (PPI): Alien control of movement contrast (ACM vs. VOL)

During suggestions of alien control of movement, the preparation interval was associated with greater functional connectivity between the SMA and bilateral posterior cingulum, right precuneus, left frontal gyrus, right angular gyrus, right postcentral gyrus (somatosensory cortex), left mid-occipital, left mid-temporal and left inferior parietal lobule (IPL). In the movement interval, FC increased between the SMA and bilateral pre- and post-central gyri (motor strip and somatosensory cortices), left frontal gyrus and left supramarginal gyrus. During the preparation interval, FC of the M1 seed increased with right cerebellum but decreased with right paracentral lobule, bilateral precuneus, and bilateral ACC (anterior cingulate cortex; $p=0.059$). In the movement interval, during suggestions of alien control of movement, FC increased between M1 and right fusiform gyrus and left thalamus (see Figure 3b and Table 3b).

Table 3. SPM functional connectivity results for the contrast between a) suggested thought insertion (TI) and voluntary writing (VOL) and b) suggested alien control of movement (ACM) and voluntary writing (VOL) for the SMA and M1 seeds.

Seed	Hemisphere	Anatomical Region	MNI coordinates x, y, z	BA	Cluster size	Z value	Cluster-level p corrected
a) THOUGHT INSERTION CONTRAST							
	Preparation Interval		**VOL > TI**				
SMA	**L**	**Mid-cingulum**	**-10, 14, 30**	**24**	**13739**	**4.60**	**0.000**
	R	Mid-frontal	28, 4, 46	6		4.38	
	L	Superior parietal	-16, -64, 46	7		4.26	
	Movement interval						
SMA	**L**	***Precuneus**	**-2, -66, 44**	**7**	**1288**	**4.18**	**0.055**
	L	Calcarine	-12, -70, 20	18		3.69	
	R	Precuneus	6, -70, 38	7		3.66	
	Preparation Interval		**TI > VOL**				
M1	**L**	**Cerebellum**	**-20, -46, -20**	**37**		**4.30**	**0.001**
	R	Superior temporal pole	30, 6, -24	38		4.01	
b) ALIEN CONTROL OF MOVEMENT CONTRAST							
	Preparation Interval		**VOL < ACM**				
SMA	**L**	**Posterior cingulum**	**-8, -46, 30**	**23**	**3780**	**6.04**	**0.000**
	R	Posterior cingulum	6, -48, 28	23		4.61	
	R	Precuneus	14, -52, 40	-		4.30	
	L	**Superior frontal**	**-20, 16, 44**	**32**	**1831**	**4.81**	**0.017**
	L	Mid-frontal	-36, 8 50	6		4.59	
	R	**Angular**	**54, -60, 24**	**39**	**1672**	**4.21**	**0.026**
	R	Postcentral	48, -10, 26	48		3.39	
	L	**Mid-occipital**	**-34, -84, 38**	**19**	**1633**	**3.59**	**0.029**
	L	Mid-temporal	-52, -60, 14	37		3.39	
	L	Inferior parietal	-52, -56, 42	39		3.35	
	Movement interval						
SMA	**R**	**Precentral**	**40, -14, 50**	**6**	**3961**	**4.49**	**0.000**
	R	Postcentral	64, -16, 34	43		4.14	
	L	**Superior frontal**	**-16, 18, 42**	**32**	**1836**	**4.21**	**0.012**
	L	Precentral	-36, -2, 50	6		4.09	
	L	Mid-frontal	-24, 10, 46	6?		3.81	
	L	**Postcentral**	**-48, -16, 32**	**3**	**1511**	**3.88**	**0.029**
	L	Supramarginal	-50, -30, 32	2		3.55	
	Preparation Interval		**ACM < VOL**				
M1	**R**	**Cerebellum**	**20, -24, -26**	**30**	**2194**	**3.85**	**0.006**
	R	***Paracentral lobule**	**4, -42, 70**	**5**	**1305**	**3.96**	**0.059**
	R	*Precuneus	12, -52, 70	5,7		3.56	
	R	***Anterior cingulate**	**8, 38, -2**	**11**	**1309**	**3.77**	**0.059**
	L	*Anterior cingulate	-8, 32, -4	11		3.34	
	Movement interval		**VOL < ACM**				
M1	**R**	**Fusiform**	**24, -32, -18**	**30**	**6289**	**4.13**	**0.000**
	L	Thalamus	-22, -26, -2	-		4.13	

Notes: *clusters approaching significance only.

BA = Brodmann Area. Significance levels corrected at p<0.01.

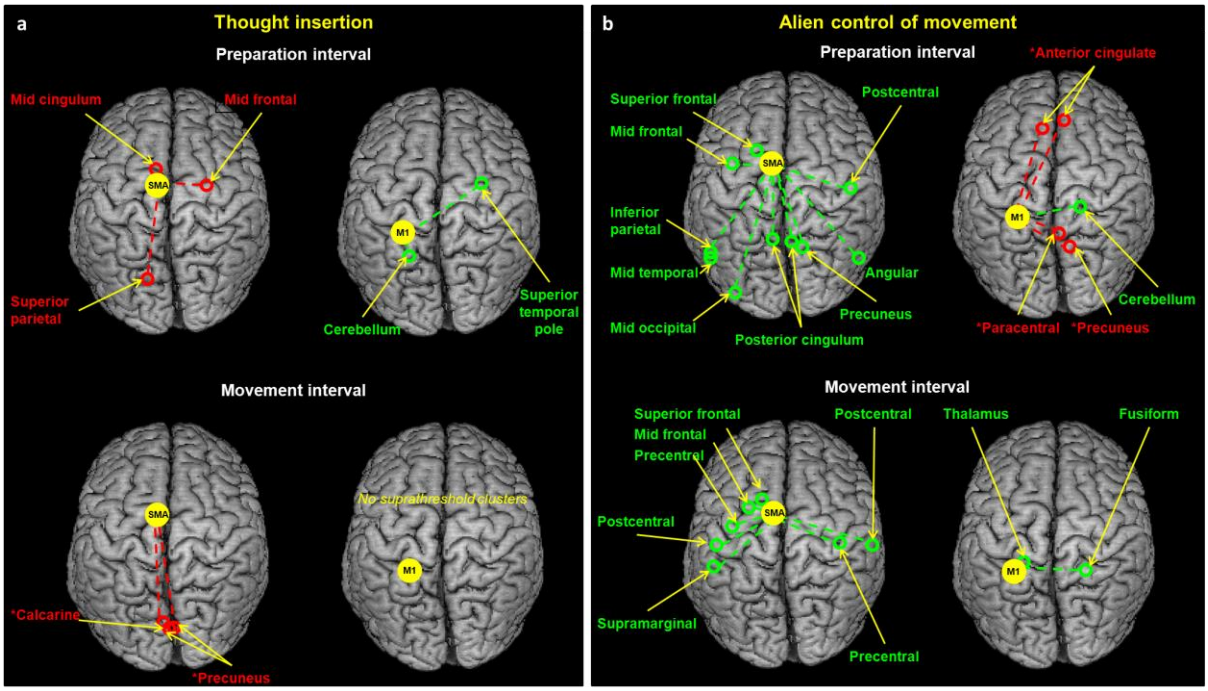

Figure 3. Schematic figure depicting functional connectivity patterns between SMA and M1 seed regions during suggestions of **a)** thought insertion (TI) and **b)** alien control of movement (ACM). Green = increased FC, and Red = decreased FC. (For indication of depth, i.e. z values, and specific peak voxel coordinates, see Table 3a, b). *clusters approaching significance only; see Table 3.

4. DISCUSSION

In this study fMRI was combined with a subjective experience of automatic writing created by hypnotic suggestion to investigate the neural bases of thought insertion and alien control of movement in healthy human volunteers. The findings demonstrate that feelings of control and ownership for thought and movement components of writing can be independently manipulated (Walsh et al., 2014). During suggestions of thought insertion, participants' ratings for control and ownership of the thought, but not the movement component of writing were reduced relative to voluntary control. During suggestions of alien control of movement, the reverse was true. Targeted suggestions, therefore selectively produced experiences of alien control for thought and movement, modelling passivity phenomena in schizophrenia as well as culturally influenced alterations in experience (such as mediumship or possession states). To investigate the neural bases of experiences of thought insertion and alien control of movement, we compared fMRI data for the voluntary and respective alien control conditions.

4.1 Functional anatomy of alien control of movement

In the alien control of movement condition, during the preparation interval (thinking of a sentence ending), the alien control of movement relative to the voluntary condition was associated with decreased activity in a network of brain regions involved in voluntary movement, including left supplementary motor area (SMA), cortical sensory-motor hand areas and thalamus. Alien control of movement was also associated with increased activation in left cerebellum and lingual gyrus in the preparation interval, and parietal cortex - specifically the left angular gyrus - during the movement

interval (i.e. writing down the sentence ending) (Table 1b; Figure 2b). These findings are consistent with the cerebellar-parietal network identified in a previous study (S. J. Blakemore et al., 2003), which also used hypnotic suggestion but in combination with PET neuroimaging, to model alien control of movement in healthy individuals. In that previous study, increased activation of a bilateral cerebellar parietal network was associated with a misattribution of movement (raising the left arm) to an external source. The cerebellar-parietal activity increases observed for experiences of alien control of writing movements in the present study confirm and extend this prior study by separating the preparation and execution stages of movement, and identifying a role for the left angular gyrus during control of writing.

The left angular gyrus has long been associated with writing - for example, lesions to this region are associated with agraphia (Gerstmann, 1942; Rusconi et al., 2009) - suggesting that increased activity in this region is specific to modulation of the perceived control and/or sensory awareness of writing movements. More generally, a cerebellar-parietal network was identified as being engaged in detecting mismatches between predicted and actual action consequences, and between feedback from different sensory modalities that convey body-related information (Botvinick & Cohen, 1998; Ehrsson, Spence, & Passingham, 2004; Synofzik et al., 2008; Tsakiris, Costantini, & Haggard, 2008). Our findings are therefore consistent with previous proposals that increased cerebellar-parietal activity during the experience of alien control of movement may result from attenuation of feedforward inhibition of somatosensory processing that occurs during voluntary movements (S. J. Blakemore et al., 2003). A prefrontal cortical origin for feedforward inhibition of sensory processing of voluntary movements has previously been proposed (Frith, 2005). Supplementary motor area (SMA) has been identified as the prefrontal source of feedforward inhibition on the basis of abolition of the sensory suppression effect for voluntary actions by transcranial magnetic stimulation of the SMA (Haggard & Whitford, 2004). The established role of the SMA in voluntary movement planning and initiation, and the present finding that SMA activity decreases during alien control of movement where self-generated movements are experienced as involuntary, is consistent with the proposed role of the SMA in feedforward inhibition. Importantly, subjective ratings of control and ownership as well as brain activations for suggested alien control of movement (ACM) and simulated alien control of movement (SIM) differed (Figure 1c,d), suggesting that participants were not engaging in simulation strategies (Table 2). In summary, findings from the alien control of movement condition are consistent with the forward model of motor control, in that they confirm and extend prior findings of parietal-cerebellar overactivation whilst assigning them to movement preparation and implementation respectively. Reduced SMA activation during preparation for alien control of movement may correspond to attenuation of feedforward inhibition of a self-generated motor intention.

4.2 Functional anatomy of thought insertion

Compared to alien control of movement, thought insertion was associated with reduced activation in a largely non-overlapping network of brain regions. Thinking of a sentence ending involves semantic and lexical processing, so that the experience of thought insertion by an “engineer” during the preparation interval entailed a loss of the sense of control and ownership of semantic and lexical content generated in response to the sentence stem. The contrast of voluntary writing with the thought insertion condition showed that during the preparation interval, this altered sense of control and ownership of semantic and lexical content was associated with a relative decrease in activity in networks supporting language, movement, and self-related processing. For example, regions showing reduced activation that are involved in language processing and writing included superior temporal gyri (BA 41/42) bilaterally and right mid-temporal gyrus (BA 21) (Howard et al., 2000; Liebenthal, Binder, Spitzer, Possing, & Medler, 2005); subcortical basal ganglia and striatum, which allow parietal systems involved in linguistic and graphemic processing to access the frontal motor systems that

mediate writing (Anderson, Saver, Tranel, & Damasio, 1993; Duffau et al., 2002); and the thalamus, which is involved in the integration of cognitive and motoric aspects of language production (Hebb & Ojemann, 2012). Visual processing areas of right inferior occipital gyrus (BA 37) and left superior occipital gyrus (BA 19) - which may support imagery (Rainville, Hofbauer, Bushnell, Duncan, & Price, 2002) during sentence generation - also showed reduced activation during the experience of thought insertion. Similarly, reduced activation was also shown in the precuneus bilaterally, brain regions involved in somatosensory integration during co-ordination of hand movements as well as contributing to the self-other distinction and sense of agency (Cavanna & Trimble, 2006). Notably, there were no measurable differences in the lexical characteristics of sentence endings, excluding this as a potential explanation of reduced activation in networks during the experience of thought insertion.

4.3 Functional connectivity of alien control

We also employed psychophysiological interaction (PPI) (Friston et al., 1997) to examine the effect of suggestions of thought insertion and alien control of movement on functional connectivity (FC) during writing. We tested the hypothesis that alien control of thought and movement is associated with reductions in functional connectivity between preparatory (SMA) and motor (primary motor cortex M1) seed regions when comparing the normal experience of writing with writing following targeted suggestions for alien control. Our main finding from the connectivity analyses was that the SMA showed reduced connectivity during thought insertion and increased connectivity during alien control of movement with largely distinct networks for type of alien control (thought insertion, movement) and phase of automatic writing (preparation, movement). M1 connectivity also showed changes in connectivity with distinct networks that varied with type of alien control and writing phase. Viewed in combination with our prior findings of reduced SMA connectivity during suggested involuntary joystick movement, these results indicate that while brain connectivity alters during the experience of alien control phenomena, changes are condition specific and do not represent a general pattern present across different types of alien control experience (Quinton Deeley et al., 2013).

4.4 Role for SMA in alien control

While thought insertion and alien control of movement were associated with distinct changes in brain activity and connectivity, both experiences of alien control nevertheless involved a reduction in activity of left supplementary motor area (SMA). This raises the question of the contribution of SMA to feelings of control and ownership of thought and movement and their loss in alien control phenomena, particularly when viewed in the context of differences in brain activation and connectivity for the respective conditions. Forward model or comparator accounts of agency (S.-J. Blakemore & Frith, 2003; Synofzik et al., 2008; Wolpert & Ghahramani, 2000) have proposed that the loss of the sense of agency results from a disruption of feedforward inhibition of somatosensory processing for self-generated movements. On this account, participants' experiences of alien control of movement in the present study are mediated by cerebellar-parietal overactivation resulting from loss of the sensory suppression effect for voluntary movements - associated with reduced SMA activation (Haggard & Whitford, 2004). By analogy it has been proposed that forward modelling also occurs during thinking, which when disrupted results in loss of a sense of agency for thoughts, as in thought insertion (Frith, 2005). In the present study, thought insertion was *not* associated with overactivation of somatosensory or other self-monitoring networks as occurred in the case of movement, further suggesting that forward model or comparator accounts of motor agency may not be applicable to experiences of thought insertion. Thus, our results are consistent with the critique of the forward model, that thoughts, unlike movements, do not have well defined sensorimotor

characteristics that could inform feedforward inhibition of self-monitoring systems (Synofzik et al., 2008).

An alternative interpretation of our findings is that apart from its proposed role as the prefrontal source of the sensory suppression effect for voluntary movement, the SMA has a more general role in contributing to the sense of control and ownership across the modalities of thought and movement (Quinton Deeley et al., 2013) In this executive control model, reduction in SMA activation underpins the loss of control and ownership occurring in thought insertion and alien control of movement respectively. Nevertheless, the consistent reduction in SMA activity underpinning loss of control and ownership appears to be task and modality dependent, as evidenced by differences in SMA connectivity between different types of alien control. A more complete cognitive account of alien control phenomena must therefore accommodate specific features of each phenomenon – for example, whether thought or movement is affected. In the case of thought insertion, an executive control interpretation of reduced SMA activity helps explain the absence of overactivation of self-monitoring systems that would be predicted by the forward model. In the case of alien control of movement, an executive control interpretation would entail that a lack of sensory suppression associated with increased cerebellar-parietal activations may underlie an altered sensory quality of unexpected movements, rather than the loss of the sense of their control and ownership per se.

An executive control model is also relevant to understanding similarities and differences between thought insertion and auditory verbal hallucinations (AVH), which are both first rank symptoms of schizophrenia but which also occur in the general population (Linden et al., 2010; Oyebode, 2008; Van Os, Linscott, Myin-Germeys, Delespaul, & Krabbendam, 2009). Auditory verbal hallucinations occur when a patient reports hearing a voice or voices when no such sound is present, whereas during thought insertion the patient "believes that thoughts that are not his own have been inserted into his mind" (Mullins & Spence, 2003). While both symptoms are experienced as intrusions generated by external agents, they differ in important respects. For example, in most cases, patients diagnosed with AVH report hearing a specific voice in external space with an identity and gender (Langdon, Jones, Connaughton, & Fernyhough, 2009), as opposed to the lack of distinct auditory characteristics of an inserted thought. Moreover, the majority of patients with schizophrenia and persistent AVH can clearly distinguish them from their thoughts (Hoffman, Varanko, Gilmore, & Mishara, 2008). Nevertheless, the fact that both AVHs and thought insertion are experienced as external intrusions raises the question of whether a shared neural mechanism reducing the sense of ownership and agency for self-generated mental contents is involved. In a study employing fMRI in patients with schizophrenia, reduced SMA activation differentiated AVH from verbal imagery (Raij & Riekki, 2012). Another study in a non-clinical sample showed that the timing of SMA activation with fronto-temporal activation was delayed during AVH relative to auditory imagery (Linden et al., 2010). These results suggest that reduced or altered timing of SMA activity might relate to the loss of the sense of ownership of one's own verbal imagery (Allen, Larøi, McGuire, & Aleman, 2008; Jardri, Pouchet, Pins, & Thomas, 2011; McGuire et al., 1995). These results relating to AVHs are consistent with our findings of reduced SMA activity and connectivity during thought insertion, and suggest a more general role for SMA in mediating the sense of control and ownership for a range of mental contents, such as experiences of movement, thought, and auditory imagery. These proposals could be directly tested in future studies employing suggestion and fMRI.

Prior studies have implicated parietal regions (BA 39/40) in the sense of agency (Desmurget et al., 2009; Spence et al., 1997). The present study provides evidence for different roles for parietal cortex in alien control of movement and thought insertion experiences. Specifically, alien control of movement was associated with increased activation of parietal cortex (angular gyrus, BA 19) during movement execution, while thought insertion during the preparation interval was associated with decreased parietal cortical activation (bilateral precuneus, BA 7). Consequently, a shared role for parietal cortex across both alien control of movement and thought insertion is not evident from these data alone.

The present study showed that suggestions for alien control of movement and thought insertion respectively were associated with small reductions in awareness compared to voluntary thought and movement following induction of hypnosis. The estimates of effect size for these reductions were considerably lower than for control and ownership. Also, a regression analysis of awareness ratings with brain activity did not show any relationships, including in areas of altered activity associated with suggested loss of control. Differences in brain activity and connectivity are therefore unlikely to be attributable to reductions in awareness during thought insertion and alien control of movement.

It could be argued that variations in kinematic factors such as force, speed, and acceleration of movement might have contributed to differences of BOLD activation between the movement conditions. While we did not use EMG recordings, writing did not differ between conditions in terms of the amount written, appearance, time of writing onset or duration. This suggests that is unlikely that differences in written output explain differences in BOLD signal between conditions. Further, kinematics cannot explain the differences in BOLD signal during the preparation period, because participants were not moving. Importantly, distinct changes were observed during the ACM and TI condition in both preparation and movement intervals, further suggesting that between condition differences cannot be attributed to kinematic differences.

We measured brain activity during thought insertion and alien control of movement in healthy volunteers in the same experimental session. However, other alien control or passivity experiences (such as “made” speech sensations, or emotions) were not investigated. Also, involuntary inhibition (e.g. limb paralysis) as well as production of a given function (e.g. involuntary movement) were not included in the same experimental session (Bell, Oakley, Halligan, & Deeley, 2011; Q. Deeley et al., 2013). Future studies could therefore employ suggestions and fMRI to experimentally model these phenomena, allowing the respective contribution of SMA and other relevant brain regions (such as parietal cortex) to be investigated across a range of alterations of agency and ownership.

The experimental paradigm combined suggestions for automatic writing and fMRI to create an experimental model of thought insertion and alien control of movement similar to those clinically reported by patients with schizophrenia, as well as culturally influenced dissociative alterations in consciousness (Deeley, 2013; David A Oakley & Halligan, 2013). In the case of culturally influenced automatic writing, implicit suggestive processes based on social modelling and implicit learning may produce similar changes in experience and brain function to the present experiment (Walsh et al., 2014). This could be directly tested in future studies with practitioners of automatic writing. In the case of schizophrenia, passivity phenomena such as thought insertion and alien control of movement may be underpinned by alterations in the function and connectivity of regional brain networks as modelled in the present study. However, in schizophrenia the altered function and connectivity of

regions and networks identified in the present study may arise from dysregulation of executive and other brain systems associated with abnormal brain anatomy and neuromodulatory systems (Fornito, Yücel, Patti, Wood, & Pantelis, 2009), rather than the effects of some form of suggestion. Nevertheless, proposals about the cross-modal role of the SMA in control and ownership of thought and movement, and the contribution of disrupted sensory suppression effects to the sensory quality rather than the sense of control of movements, could inform future investigations of passivity phenomena in schizophrenia.

4.5 Conclusions

In conclusion, the present study has clearly demonstrated that thought insertion, as well as alien control of movement, can be experimentally studied. During the experience of thought insertion, there was no evidence of increased activity in regions involved in self-monitoring as predicted by comparator or forward models. Specifically, reduced activity in language production regions, and not overactivation of cerebellar-parietal regions, was present during thought insertion. By contrast, previous findings of parietal cortical and cerebellar overactivation during alien control of movement were confirmed and extended by showing these to be restricted to movement preparation and implementation respectively. Thought insertion and alien control of movement were also associated with discrete changes in the functional coupling of SMA and M1. While thought insertion and alien control of movement were associated with distinct changes in brain activity and connectivity, both experiences involved a reduction in activity of left SMA. Collectively these findings suggest that the SMA plays a key role in the generation of alien control phenomena, as a high level executive system involved in the control and ownership of thought and movement.

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